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Drought detection of West Java's paddy field using MODIS EVI satellite images (case study : Rancaekek and Rancaekek Wetan)

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Abstract

Nowadays, drought phenomenon occurred in several area in Indonesia. The length of the dry season, especially in the southern equatorial allegedly caused by El Nino phenomenon. This causes crop failures in many center area of agriculture. West Java Province as one of the centers of agricultural activities in Indonesia experienced a severe drought within a period of 6 months (April-September in 2003). The monitoring of drought is useful to understanding the characterization of drought itself. In the next period, we can decide what should we do to decreased the impact of this phenomenon. The study aimed to implement Breaks for Additive Seasonal and Trend (BFAST) algorithm for detecting and monitoring paddy field areas experiencing drought in The West Java during the period 2000-2015. This study used remote sensing data to study the response of vegetation on the drought phenomenon. MODIS EVI time series were decomposed into seasonal, trend, and remainder component using BFAST which enables the detection of trend changes within the time series. The result of study shows that BFAST able to detect drought in MODIS EVI time series. The result also compared to a new drought index, called SPEI.

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Keywords: BFAST; drought; dry season; MODIS EVI; paddy field; West Java.

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1. Introduction

The agricultural sector is one of the leading sectors that can fulfill our primary needs every day. Especially rice for Indonesian people. Rice produced from paddy where the paddy can be cultivating in paddy field area. According to Data and Information Center, Ministry of Agriculture 2010, West Java Province consist of paddy field area with a number are 925,565 hectare divided into 673,991 hectare of irrigated paddy field area and 251,574 hectare of non-irrigated paddy field area. The paddy field area and its productivity year to year has decreased caused by several factors. One of the factors that affect to agricultural sector productivity is drought phenomenon.

Drought phenomenon is the impact of global climate change, El Nino, and La Nina. In Agricultural sector, the main factor of agricultural production sustainability is managing climatic variability. Because it's critical condition, drought must be seriously managed in order to make stable production. The main cause of climatic variability is the El Nino Southern Oscillation (ENSO). During El Nino, some regions encounter lack of precipitation and vice versa during La Nina. Both El Nino and La Nina are natural phenomena. It is a normal condition and periodically occurred in a certain pattern [1].

Based on above explanation, the drought's phenomenon must be anticipated in order not to affect agricultural production sustainability. One way to anticipate this problem is monitoring drought at regional to global scales. This task is not easy because the characteristics of drought in each region is not the same and has different consequences [2]. Remote sensing is one of the most appropriate methods to do observations on the wide area and provide consistent data and frequency of data which are relatively quick and appropriate to capture the result of many processes that caused disturbances [3]. It is a powerful tool to produce land-use and land cover maps to identify the real-time process of change, and their locations, either in global or regional scale [4].

Remotely sensed data obtained from satellite sensor such as MODIS. MODIS satellite imagery provides data in moderate resolution. MODIS product that was used is Enhanced Vegetation Index (EVI) datasets to see the response of vegetation on drought phenomenon. It this study, we selected MOD13Q1 with 250 m spatial resolution and 16-days temporal resolution. MOD13Q1 can provide near-real-time data over large areas in relatively high resolution, has been widely used for vegetation condition monitoring, and also provide the seasonal dynamic for the paddy field patterns [5]. The algorithm that was used to detect drought in this research is Break For Additive Season and Trend (BFAST). BFAST can estimate the change in time series data and decomposed it into three components (seasonal, trend, and remainder components). The result of BFAST change detection furthermore will be adjusted to drought index known as The Standardized Precipitation-Evapotranspiration Index (SPEI). The SPEI fulfills the requirements of a drought index since its multi-scalar character can be used by different scientific disciplines to detect, monitor and analyze droughts.

2. Methods

2.1. Study area

The study focused in West Java Province that geographically located in latitude 5°50'- 7°50'S and longitude 104°48' - 108°48' E and the detailed of location that suffering drought at two locations: Rancaekek and Rancaekek Wetan, Bandung District. West Java Province has a good potential in agriculture, almost all area has a same potential agriculture. The main agricultural products in this area is paddy. Paddy field area in Bandung District was measured 88,667 hectare in 2013 [14]. Bandung District has high rainfall intensity [6] between 2000-4000 mm/year.

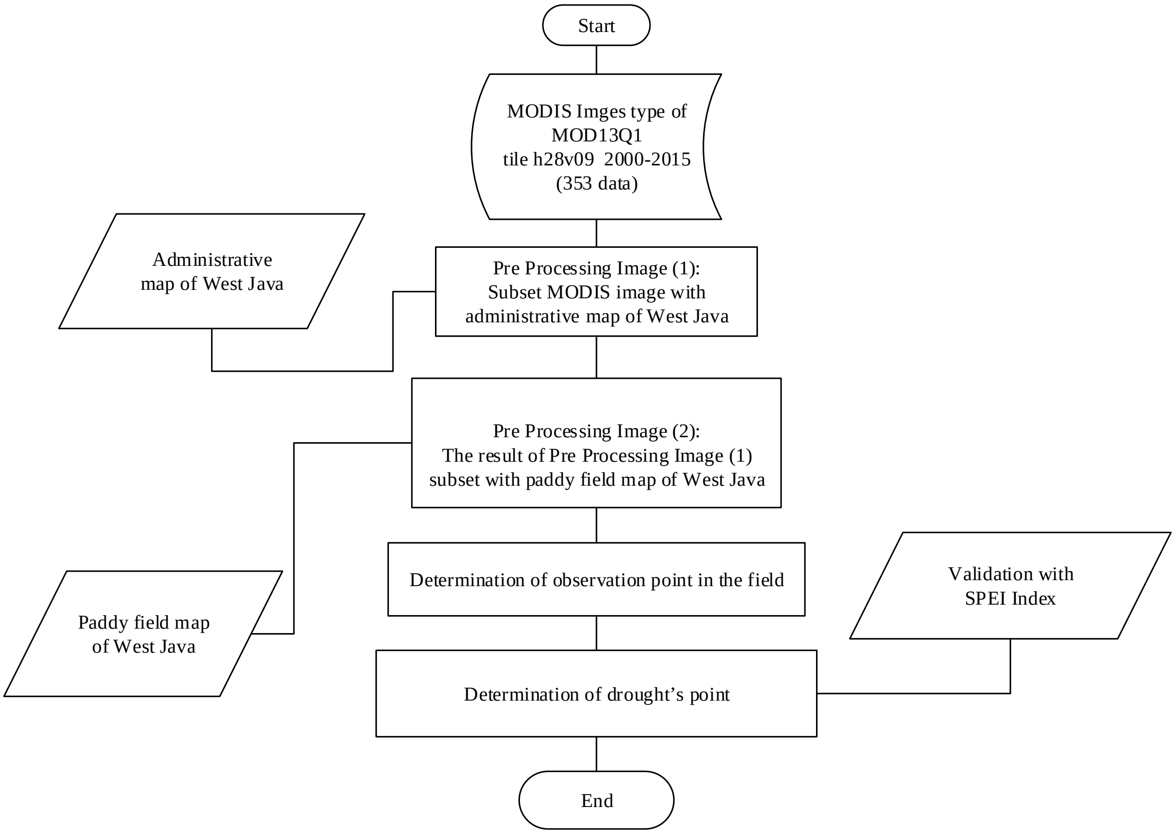

Fig. 1. Flowchart of study

2.2. MODIS EVI data

EVI is is an 'optimized' vegetation index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences. EVI is more responsive to determinate the canopy structure variation, including the Leaf Area Index (LAI), type of canopy, plant physiology and canopy architecture [7]. MODIS EVI was selected because it is very sensitive to vegetation including paddy. EVI is computed following this equation [7]:

$$EVI = G \times \frac{(NIR-RED)}{NIR+C1\times RED-C2\times BLUE+L} \tag{1}$$

where NIR/red/blue are atmospherically-corrected or partially atmosphere corrected (Raleigh scattering and absorption of ozone). L is the background adjustment canopy to overcome the transasi non-linear, differential NIR and RED of the canal that goes through the vegetation canopy with value 1, C1 = 6 and C2 = 7.5 are coefficients designed to correct for aerosol scattering and absorption, and G = 2.5 is a gain factor [7]. The MODIS image was acquired from February 2000 to June 2015.

Fig. 2. Map of the study area showing West Java Povince

2.3. The Standardised Precipitation-Evapotranspiration Index (SPEI)

SPEI was used to assess the result of BFAST Algorithm on drought detection. BFAST estimate the drought phenomenon with breakpoints in time series of MODIS EVI data. The SPEI fulfills the requirements of a drought index since its multi-scalar character can be used by different scientific disciplines to detect, monitor and analyze droughts. Like the sc-PDSI and the SPI, the SPEI can measure drought severity according to its intensity and duration, and can identify the onset and end of drought episodes. The SPEI allows comparison of drought severity through time and space since it can be calculated over a wide range of climates, so can the SPI. Moreover, Keyantash and Dracup [8] indicated that drought indices must be statistically robust and easily calculated, and have a clear and comprehensible calculation procedure. All these requirements can be fulfilled by the SPEI. However, a crucial advantage of the SPEI compared to other drought indices that widely used is the ability to consider the effect of PET on drought severity. Its multi-scalar characteristics enable to identify the different drought types and impacts in the context of global warming.

2.4. Breaks For Additive Seasonal and Trend (BFAST)

BFAST is one of the packages from R statistical computing software. BFAST method was invented by Jan Verbesselt. BFAST integrates the decomposition of the time series into trend, seasonal, and the remaining components to a method for detecting and characterizing changes in the time series. BFAST iteratively estimate the time and the number of sudden changes in time series, characteristic changes with magnitude and direction. It can be used to analyze various types of time series data (e.g., Landsat and MODIS) and also be applied to other disciplines related to seasonal time series or not, such as hydrology, climatology, and econometrics. The algorithm can be extended to mark the changes detected with information about the paired parameters of piecewise linear models [9]. BFAST equation can be seen as follow [9]:

$$\boldsymbol{Y_t = T_t + S_t + e_t (t = 1 \ldots . n)} \tag{2}$$

Where the Y_t is observed EVI data at time t in the time series, T_t is trend component, S_t is seasonal component and e_t is remainder component. It assumed that T_t is piecewise linear with spesific segment slope and tapping on different segments of $m + 1$ ($m \geq 0$). Therefore, there is m breakpoints τ_1^* , ..., τ_m can be seen in the following equation:

$$T_t = \alpha_i + \beta_i t \; (\tau_{i-1}^* < t < \tau_i^*) \tag{3}$$

Where i = 1, ..., m and we defining τ_0^* = 0 and τ_{m+1}^* = n . St is piecewise phenological cycle on various segments divided with seasonal breakpoints, $\tau_1^\#$, ..., $\tau_p^\#$ ($\tau_0^\#$ = 0 and $\tau_{p+1}^\#$ = n), is shown as:

$$\boldsymbol{S_t = \Sigma_{k=1}^{K} \left[Y_{j,k} \sin\left(\frac{2\pi kt}{f}\right) + \theta_{j,k} \cos\left(\frac{2\pi kt}{f}\right)\right] \left(\tau_{i-1}^\# < t < \tau_i^\#\right)} \tag{4}$$

Where the coefficient is Yj, k and $\theta j, k$, K is number of harmonic pattern, and f is frequency. Breakpoints in trend component and seasonal component detected iteratively as follows : (1) breakpoints τ_1^*, ..., τ_m expected using residual-based moving sum (MOSUM) test and assessed with minimizing Bayesian Information Criterion (BIC) of adjusted data seasonally $Yt - St$, where St first found with STL method; (2) T_t, α, and β expected using a robust regression based M-estimations; (3) breakpoints $\tau_1^\#$, ..., $\tau_p^\#$ are equally expected using MOSUM dan BIC from de-trended data $Yt - T$t; (4) revision of S_t expected based on M-estimations; (5) Parameter of estimations in BFAST is iteration until the number and position from breakpoints is unchanged.

3. Results

3.1. The result of BFAST analysis

Based on the ground check, we processed some points using BFAST algorithm. The result of the analysis showed the two points indicated experiencing the drought. Those points are located in Bandung District exactly in Rancaekek and Rancaekek Wetan. The signal from EVI data of these location showed that the lowest signal reached minimum index in March 2003. The EVI data are shown in Fig. 3.

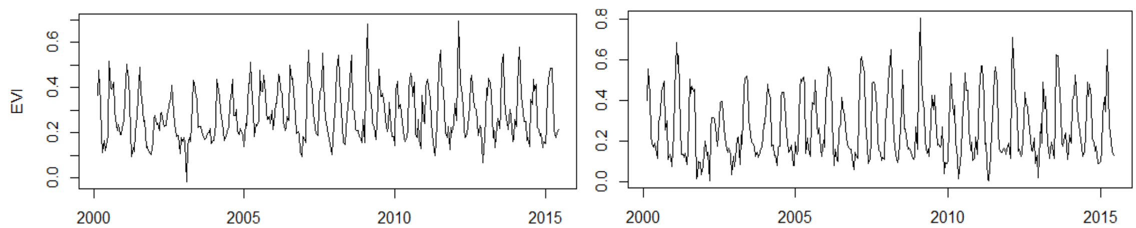

Fig. 3. Original evi data from two locations, (a) Rancaekek and (b) Rancaekek Wetan

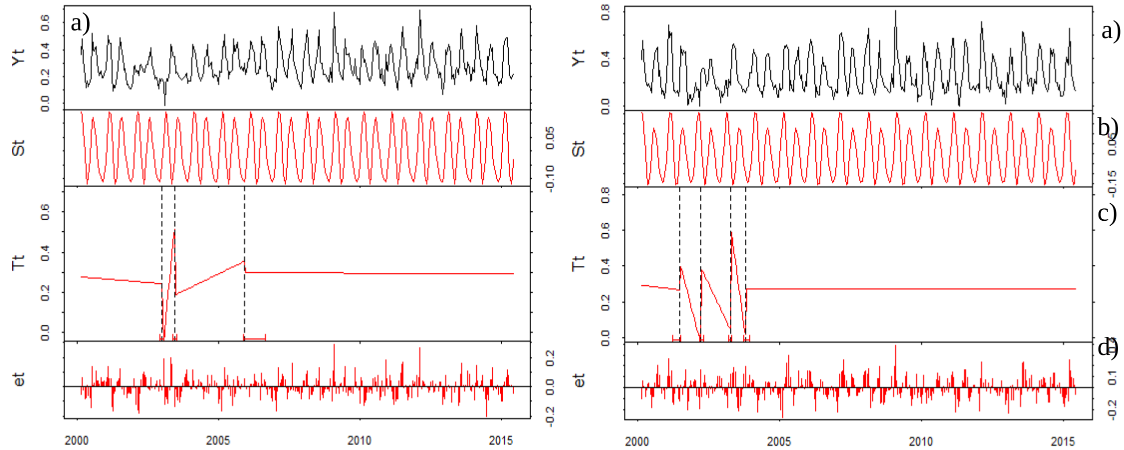

Fig. 4. (a) Time series of MODIS EVI, 2000-2015. The time series was decomposed into (b) seasonal (c) trend and (d) remainder components using BFAST algorithm. The abrupt, lowest signal (reached minimum index) in 2003 indicates the effect of drought on vegetation.

Breakpoints can detect the trend component but not the seasonal component. Trends in long time series of vegetation data usually consist of gradual changes, but may also include more abrupt changes. Gradual changes normally reflect long-term changes in other factors such as land management, land degradation, and inter-annual climate variability such as temperature variability in boreal/arctic areas [10]. Abrupt changes are normally caused by disturbances such as fire, flood, urbanization, insect attack, or drought [11].

Overall, different types of changes (gradual, abrupt, seasonal) may be represented in a time series of remotely sensed vegetation index. Irrespective of the physical causes of the changes, they share underlying mathematical properties (e.g.linearity or nonlinearity), which allow them to be detected and quantified using the techniques of time series analysis [12].

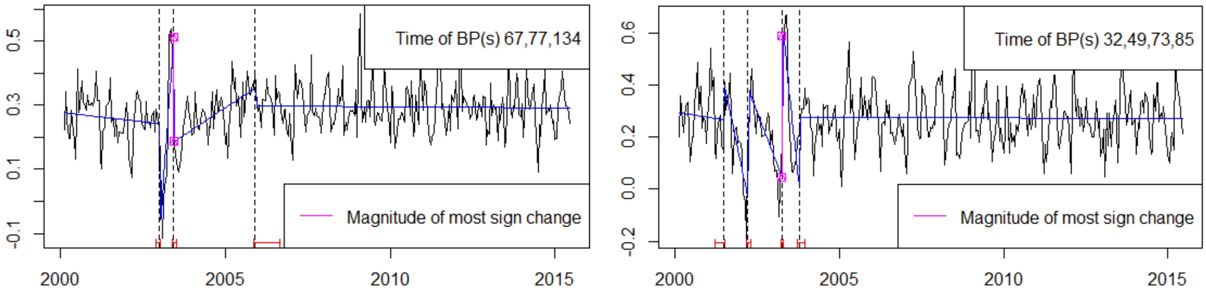

Fig. 5. Breakpoints in trend components of BFAST algorithm

Breakpoints in Rancaekek detected in 67, 77, and 134 of MODIS EVI data. According to Fig. 5, the lowest signal that reached minimum index (indicated drought phenomenon) was detected in 67 until 77 of these data. The time period of drought allegedly during five months more (if one data of MODIS is 16 days, then ten data of MODIS is 160 days). Another location in Rancaekek Wetan, breakpoints detected in 32, 49, 73, and 85 of MODIS EVI data. The lowest signal that reached minimum index (indicated drought phenomenon) was detected in 32 until 49 of these data.

3.2.Temporal patterns of the drought

The impacts of drought can be seen in temporally because it is so clearly visible year by year in time series data. Fig. 5 shows the 3-monthly SPEI for Rancaekek and Rancaekek Wetan, both of this location indicated experiencing the drought. The intensity of drought reached a maximum condition in March 2003. The drought severity was observed in 2003, and in other years the intensity of drought experienced fluctuating value.

Fig. 6 shows that the histogram was declined in 2003, both of locations (Rancaekek and Rancaekek Wetan). It means at that time the drought phenomenon was occurred at those locations. The SPEI allows comparison of drought severity through time and space, and it can be calculated over a wide range of climates. It’s almost approaching the actual conditions, because the parameters that used were closely related to actual climatic condition such as precipitation and PET (Potential Evapotranspiration) and combines the sensitivity of PDSI with changes in evaporation demand and the multi-temporal nature of the SPI. The SPEI entered the factor of temperature effect. It is almost similar with SPI. Moreover, SPEI analysis is based on water balance thus it is really suited to detect, monitor, and explore the impacts of global warming on drought conditions [13].

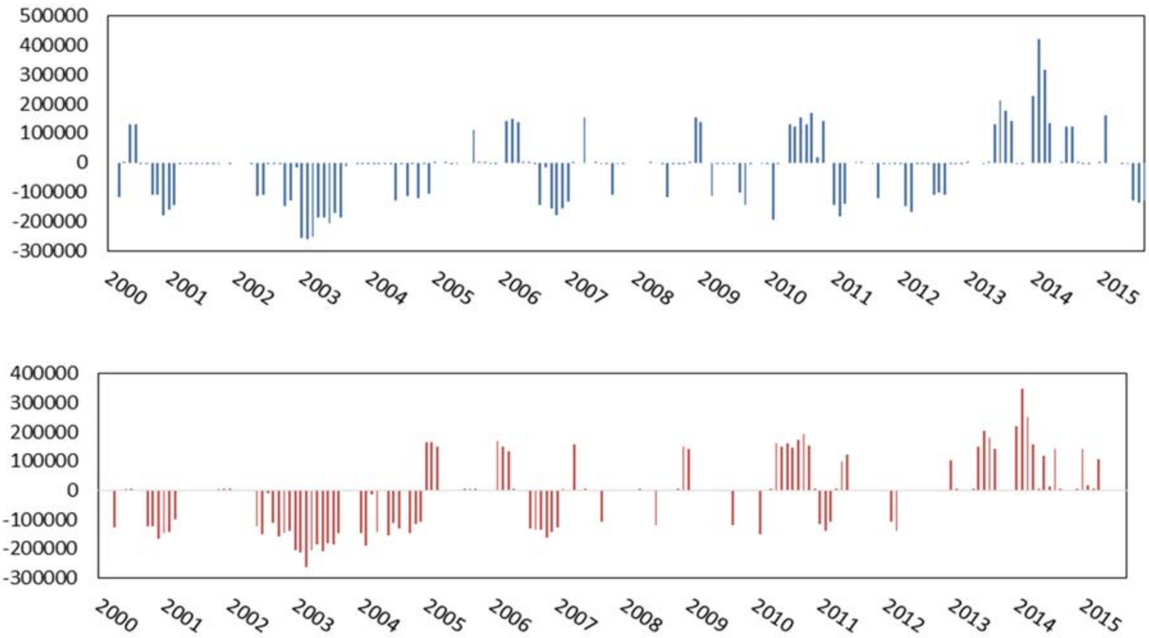

Fig. 6. Three-monthly SPEI for (a) Rancaekek and (b) Rancaekek Wetan

4. Conclusion

Drought detection in West Java province (focused on two locations, Rancaekek and Rancaekek Wetan) as revealed by MODIS EVI data have been examined in this study. MODIS EVI data able to show the response from the vegetation on the drought condition. This can be conducted by using BFAST algorithm. BFAST algorithm is able to detect changes in the trend components on severity drought by estimating the time and number of sudden changes in time series, characteristics change with magnitude and direction. To assess the result of BFAST analysis, a new drought index known as The Standardised Precipitation-Evapotranspiration Index (SPEI) was used.

BFAST breakpoint is able to mark the change in the trend. Marked trend was indicated as drought phenomenon occurrence. Trend components in BFAST analysis show the magnitude of most sign changes in time series MODIS EVI data. The time of detected change in BFAST is same with SPEI. BFAST estimates the magnitude of most sign changes in 2003 and the SPEI shows at that time (2003) the intensity of drought reached the maximum. So, changes in agricultural land (e.g., paddy fields) that occurred were caused by the drought phenomenon.

Changes detection within time series are the first step towards understanding the governing processes and drivers. Here, BFAST was applied to MODIS EVI time series data to detect changes in time series during the severity drought.

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